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Technical Report EL-93-24
December 1993

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US Army Corps of Engineers
Waterways Experiment Station

Imaging Smolt Behavior on Extended-Length Traveling Screens, McNary Dam: 1991 Pilot Study

by John Nestler
Environmental Laboratory

Robert Davidson
Hydraulics Laboratory

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Prepared for U.S. Army Engineer District, Walla Walla

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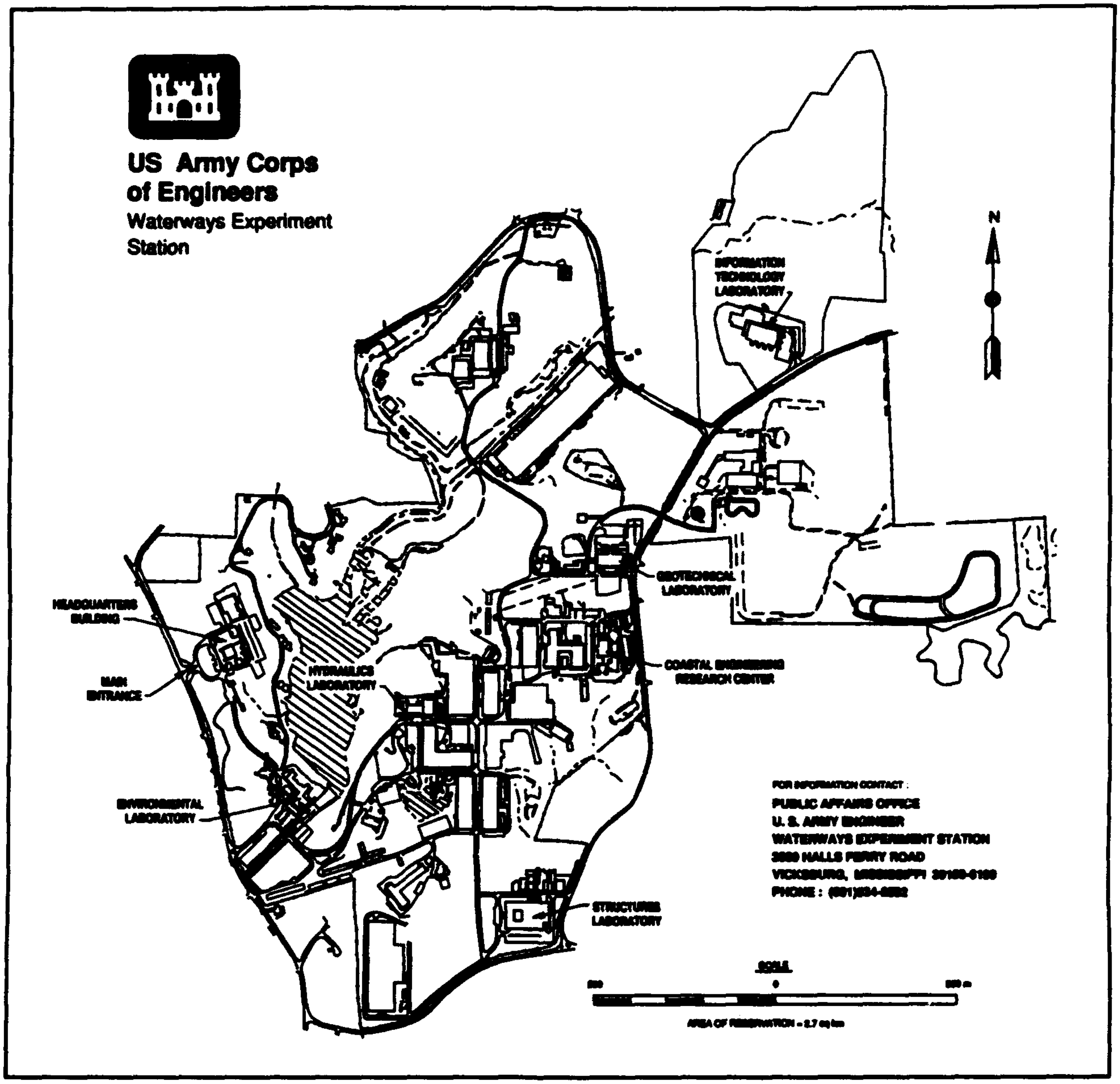

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Preface

This study reported herein presents conclusions derived from imaging smolt behavior on extended-length traveling screens at McNary Dam. This report was prepared in the Environmental Laboratory (EL) and Hydraulic Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was sponsored by the U.S. Army Engineer District, Walla Walla, and was funded under the Intra-Army order for Reimbursable Services No. E86920081 dated 24 February 1992.

The Principal Investigators of this study were Dr. John Nestler of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), EL, and Mr. Robert Davidson of the Locks and Conduits Branch (LCB), Hydraulic Structures Division (HSD), HL. This report was prepared by Dr. Nestler and Mr. Davidson under the direct supervision of Dr. Mark Dortch, Chief, WQCMB, and under the general supervision of Mr. Donald L. Robey, Chief, EPED, and Dr. John Harrison, Director, EL. It was also prepared under the direct supervision of Mr. John George, Chief, LCB, and under the general supervision of Mr. Glen Pickering, Chief, HSD, and Mr. Frank Herrmann, Director, HL. Technical reviews by Messrs. Gene Ploskey and Tom Cole are gratefully acknowledged.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters

1 Introduction

Background

The North Pacific Division operates a number of hydropower dams on rivers that support valuable anadromous fisheries. Extensive bypass facilities have been installed at these dams to intercept out-migrating salmon smolts before they enter turbines. The first component of a bypass facility encountered by smolts is a slanted screen of relatively fine mesh or bar spacing. The screen intercepts and guides smolts up the gate well and then into a transport system that passes them around the dam and into the tailrace either for immediate release or for holding until later transport. Several structural modifications are being considered by the U.S. Army Engineer District, Walla Walla, to increase the efficiency of the screens.

The Walla Walla District is evaluating a plan to install extended fish screens at McNary Dam based, in part, on initially promising results obtained from tests of simulated extended-length screens at Lower Granite Dam in 1987, 1989, and 1990. However, tests at Lower Granite Dam indicated that extended-length screens may also result in an unacceptably high level of impingement. Impingement mortality rates greater than 1 percent negate increased fish guidance efficiency (FGE) benefits of 5 percent projected for spring chinook with extended-length screens at McNary Dam. Concomitantly, an impingement mortality rate greater than 3 percent negates the projected 15 percent benefit in FGE for fall chinook. There also remains considerable uncertainty regarding whether there are differences in impingement rates on submerged traveling screens (STSs) and Submerged Bar Screens (SBSs). These questions, and others regarding the detailed response of out-migrating smolts to bypass screens, must be answered for the Walla Walla District to optimally design and operate fish protection systems at McNary Dam and other dams where extended-length screens might be installed.

Entrainment and impingement of smolts in the hydraulic environment in the vicinity of prototype screens rarely have been quantified through direct imaging. Such information is needed to optimize screen design and operation (Fletcher 1985). The rigorous hydraulic environment between turbine intakes and screens, low light levels, and high turbidity has

prevented application of conventional imaging technologies to directly observe the performance of fish protection systems. Consequently, there is considerable uncertainty regarding what environmental or structural factors affect screen contact or impingement rates. New developments in underwater video equipment may now allow direct imaging of smolts in the rigorous hydraulic, turbid, low-light environment of water intakes.

Objective

The objective of this pilot study is to design and deploy an underwater video camera system, using existing new technology to (a) assess smolt screen contact and impingement rates on extended-length STSs (ESTSs) at different screen locations and at several turbine loadings and (b) describe the response of smolts as they approach and are intercepted by ESTSs. Imaging results will be overlaid on a template of physical and hydraulic conditions on the screen surface determined previously by the Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS.

Preliminary findings from this pilot study can be applied to McNary Dam and could be useful for other Corps of Engineers (CE) dams on the Columbia and Snake Rivers, providing information for conducting detailed imaging studies in future years. Preliminary results obtained for McNary Dam will provide general insight into the design and operation of bypass systems at other CE Columbia River system dams. However, additional detailed studies would have to be conducted at McNary Dam and at other Columbia River Dams to identify and incorporate the unique environmental conditions and design and operation features at each dam.

2 Materials and Methods

Site Description

McNary Dam is a multipurpose CE project located in south central Washington State on the Columbia River at River Mile 292 (Figure 1). It was completed in 1954 and presently consists of (oriented from south to north) two small house units to provide internal power requirements, a powerhouse with 14 Kaplan turbines (numbered 1 to 14, south to north), a spillway structure with 22 gates, and a navigation lock (Figure 2). Power generation releases from McNary Dam (Lake Wallula) are on a run-of-the-river basis and are closely governed by releases from the dams upstream and the flow requirements of the power projects downstream.

McNary Dam has extensive facilities to aid in the collection and transportation of both adult and juvenile migrating fishes. Adult fish are provided passage by a fish ladder located by each shore. Downstream migrating fingerlings are collected by STSs located in the turbine penstocks (Figure 3). These screens divert young fish away from the turbines and into a flume that carries them to a holding area where they await transportation downstream.

Screen Description

The ESTS assembly consists of two frames: an outer support frame designed to slide in the gate slots for screen deployment and retrieval and an inner frame (attached to the outer frame) providing the structural support for the screen mesh (Figure 4). The outer frame is made up of two support beams and two connecting tube beams. The inner frame is made up of two outer support beams, one center support beam, and several connecting box beams. Porosity plates span the space between the outer support beams of the inner frame. They are bolted from each outer support beam to the intermediate support beam. Porosity plates are used to reduce water velocity through the screen. A nylon mesh screen material is wrapped around the perimeter of the inner frame on each side of the center support beam to form two separate screen surfaces. The mesh from each screen

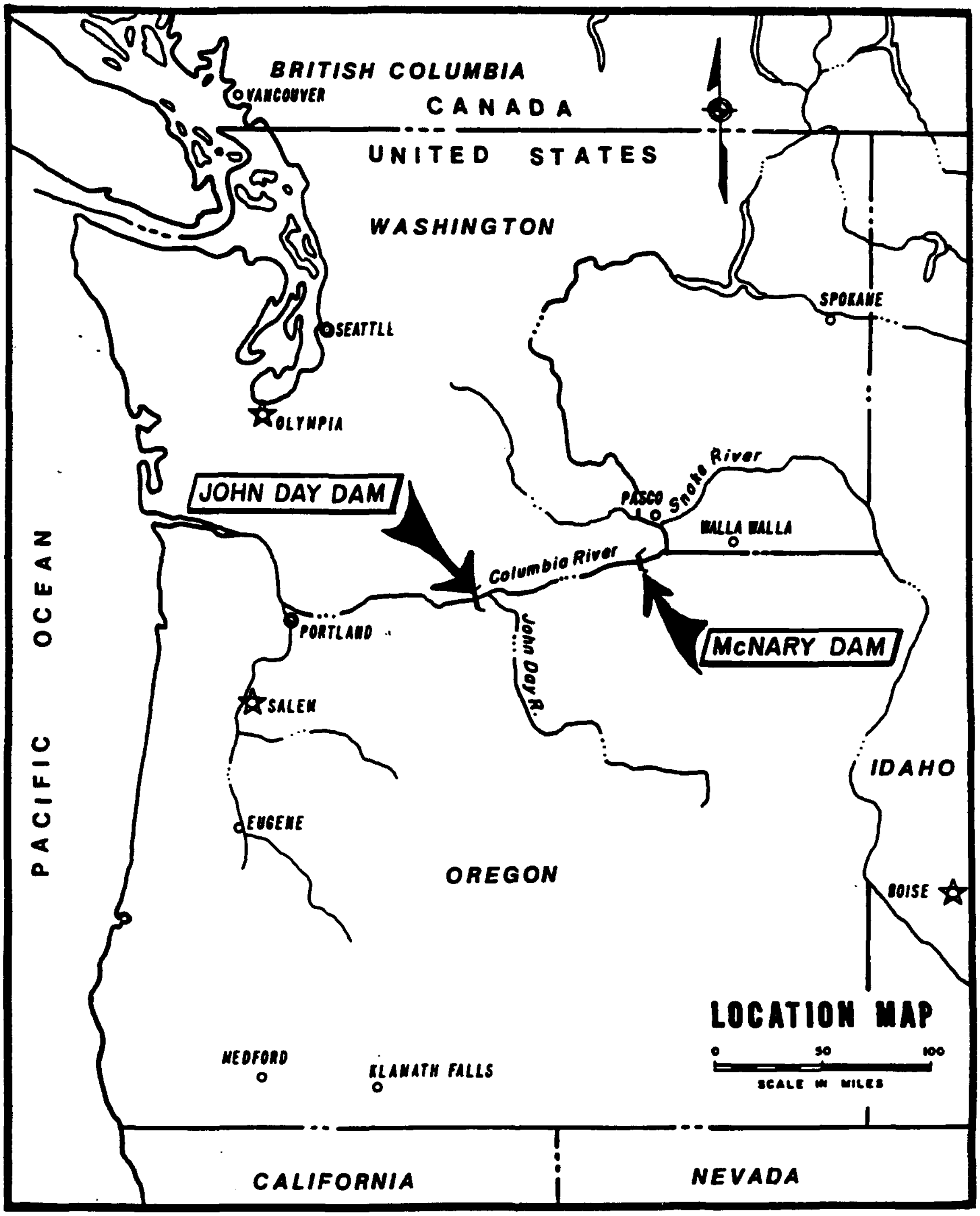

Figure 1. Site map showing location of McNary Dam on the Columbia River

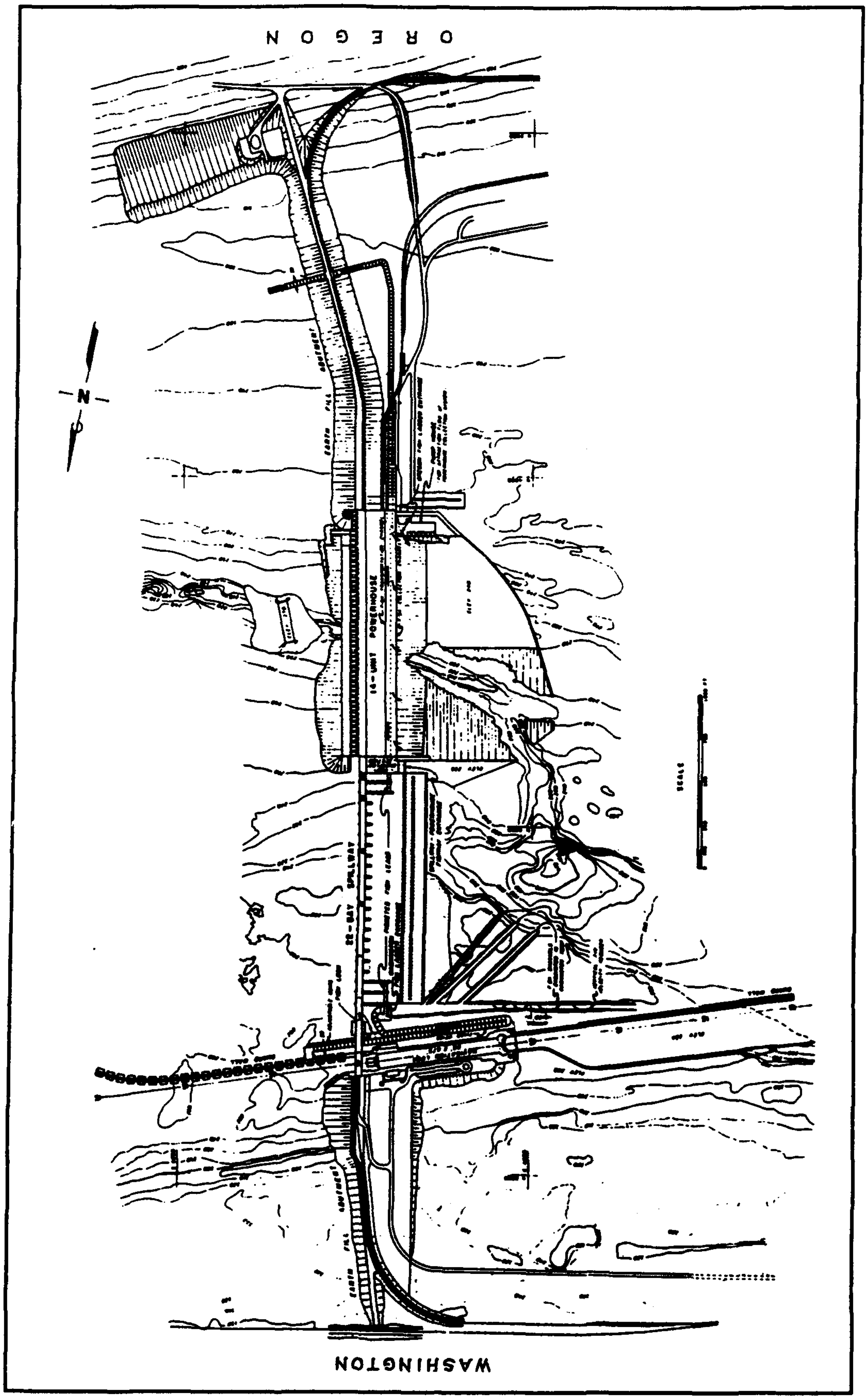

Figure 2. Plan view of McNary Dam showing approach channel configuration and location of powerhouse and spillway

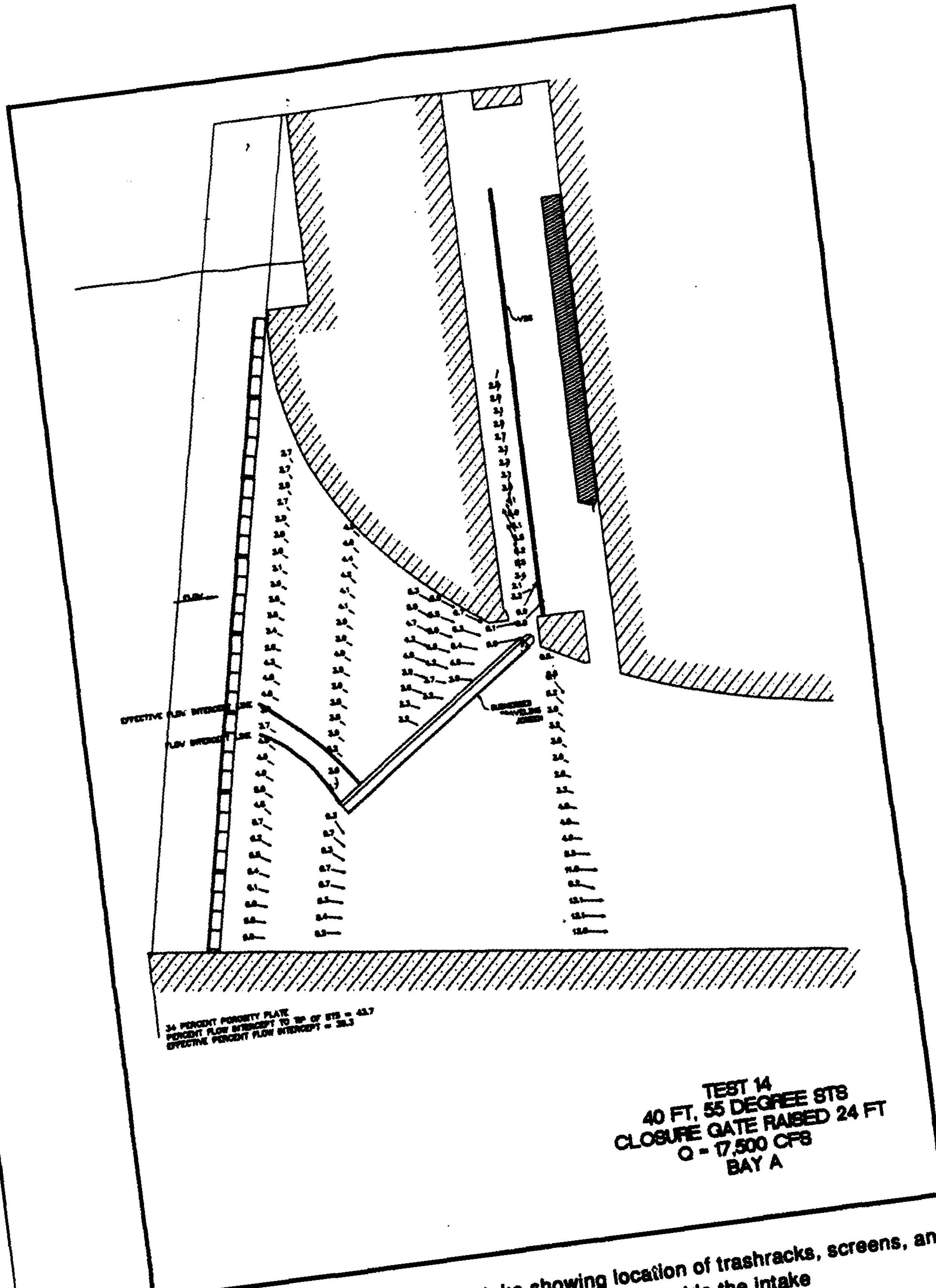

Figure 3. Profile view through intake showing location of trashracks, screens, and gate well. Velocity vectors indicate flow field inside the intake

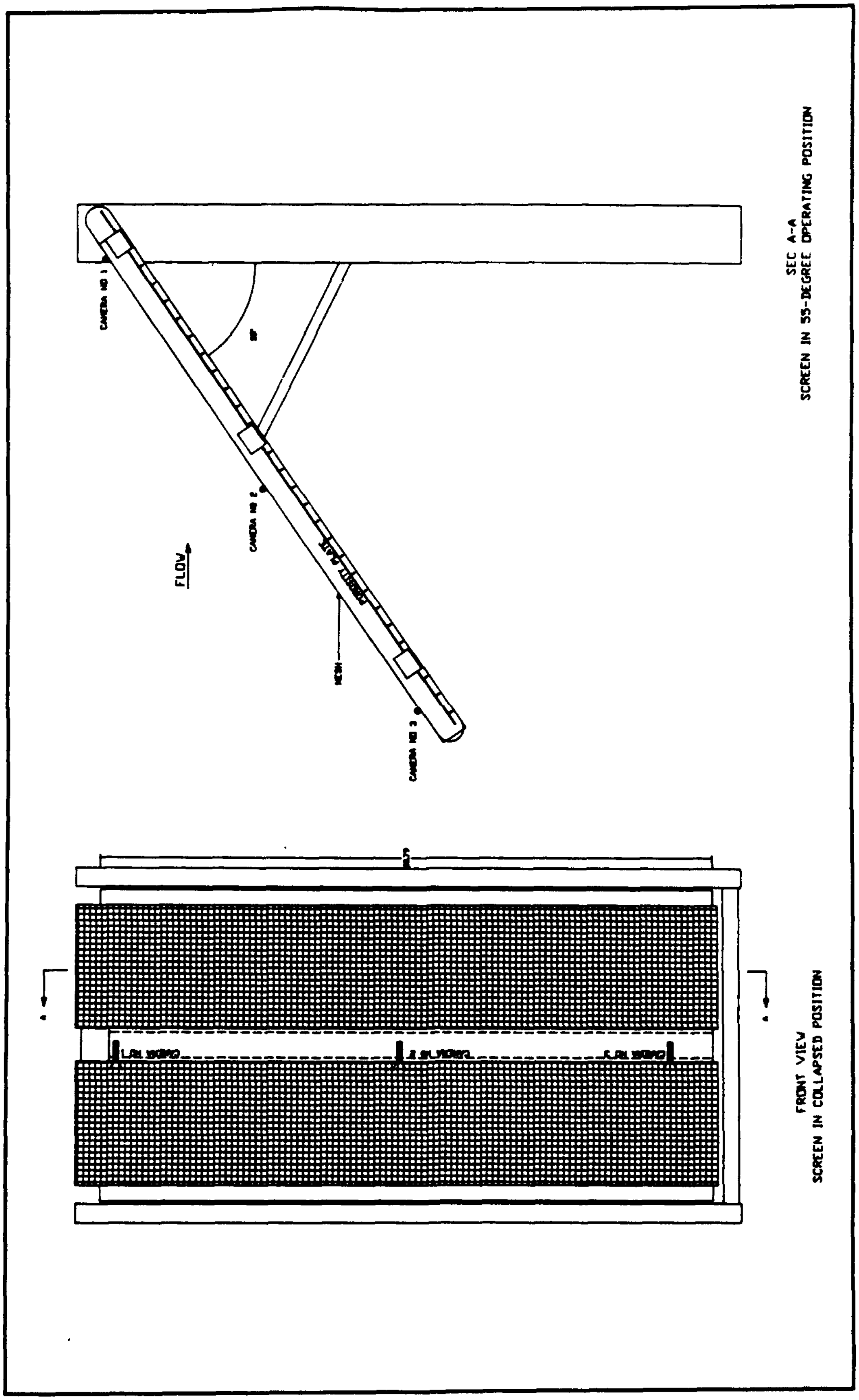

Figure 4. General configuration of traveling screen with approximate locations of video cameras indicated

surface extends from the center support beam to the outer support beam. The screens are rotated periodically to remove debris from the screen surface.

The inner frame is pinned to the outer frame at a pivot point near the top of the screen asssembly, and the inner frame is supported by two strut arms deployed from the bottom of the screen assembly. The ESTS is deployed by lowering the screen assembly down a bulkhead slot in a collapsed (vertical) position. Once it reaches the desired elevation, the strut arms are extended, which causes the inner frame to rotate about the pivot point. The strut arms are extended until the inner frame has been rotated to its desired operating angle.

Camera and Illumination System Description

The efficacy of several underwater video cameras were evaluated in an experimental flume at WES in early July 1991. Although not completely light tight, the flume could be sealed enough to approximate optical conditions within the intakes. Based on these tests, it was determined that Outland Technology UWC-160 underwater color TV system had adequate image quality with minimal lighting to meet the study objectives. Camera specifications are listed in Appendix A.

Sampling Period and Conditions

Pilot studies were performed between 2000 and 0200 hours at McNary Dam on 17-20 July during FGE testing conducted by the National Marine Fisheries Service (NMFS). A freshet occurred on July 8, 1991, causing an increase in water turbidity that reduced the quality of the video images and reduced imaging distance by about 50 percent.

Summary Intake Configuration and Hydraulic Conditions

Intake configuration

The top of the bellmouth intakes at McNary Dam is located at elevation 329.5, a depth of 10.5 ft[1] at normal pool. The bottom of the intake is

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vii.

located at elevation 233.6. Each intake is guarded by steel trashracks located approximately 20 ft upstream of the toe end of the ESTS.

Screen surface and gate well

Findings by the WES Hydraulics Laboratory indicate that the diversion screens generate complex hydraulic patterns that vary across the surface of the screen and change as screen angle or unit loading is altered. In addition, the center and side supports of the screen probably produce local flow anomalies. The ability and propensity of fishes to respond to local flow conditions in rivers is well known, and it seems reasonable to speculate that the complex hydraulic field on the screen surface would result in localized differences in smolt behavior and impingement.

Imaging will occur at multiple points on the hydraulic field to ensure that screen contact and impingement behavior of smolts is adequately quantified across the range of hydraulic conditions on the screen surface. Results from the imaging will be presented in terms of the hydraulic conditions associated with each camera location. By relating impingement and fish behavior to hydraulic conditions on the screen face, it will be possible to integrate the effectiveness of the screen across its entire face or to identify localized zones that require redesign.

The ESTS that was video-monitored had an angle of 55 deg (as measured from the vertical), a porosity of 34 percent, a unit loading that varied between 12,000 to 16,000 cfs at 2,000-cfs increments, and produced a hydraulic field depicted in Figure 5 (for 17,500 cfs). As a general guide, the screen surface can be separated into three different zones—upper third (nearest the gate well), middle third, and lower third (nearest the toe). Variation in angle of flow is the critical feature of the flow field in these three zones. In the middle zone, the flow is perpendicular to the surface of the screen, and the flow passes directly through the screen. A passive object caught in this flow may be impinged and pressed onto the screen surface. In the upper third of the screen, the flow lines become increasingly parallel to the surface of the screen and move towards the gate well. A passive object caught in this flow feature would be either entrained into the gate well or pushed towards the gate well on the screen surface. In the bottom third, the flow lines become increasingly parallel but moving away from the gate well. A passive object caught in the lower third of the screen would be either pressed into the screen surface or pushed towards the toe of the screen, under the lip of the screen, and into the turbine.

Imaging System Deployment on ESTS

The camera mounting system used at McNary Dam had to allow normal deployment of the ESTS through the gate slots without a need for divers for attachment and inspection. WES staff, with assistance of

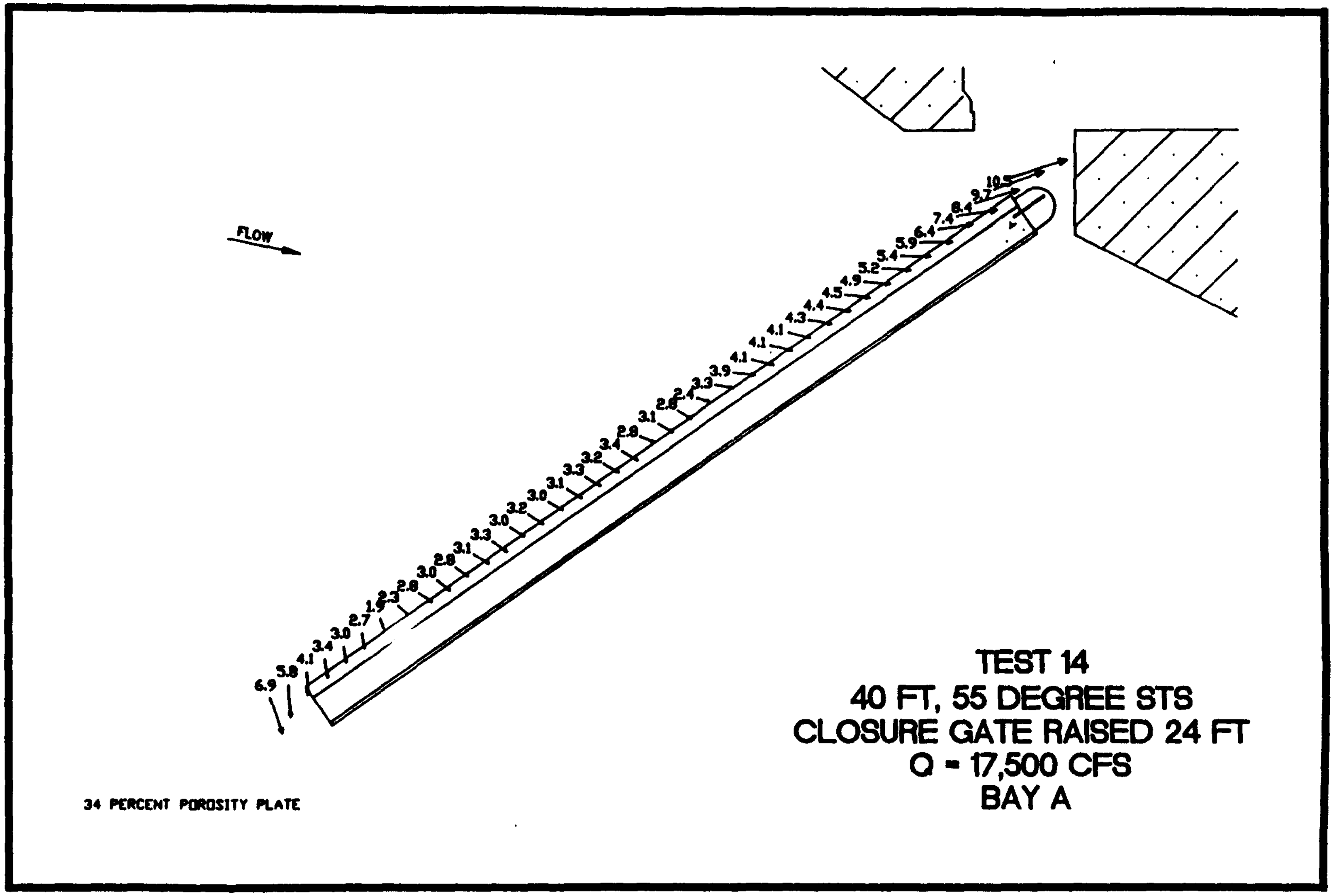

Figure 5. Side view of velocity distribution on surface of traveling screen. Note how direction of flow vectors change from toe to top of screen

McNary Dam project personnel, attached the light and camera system to the screen, secured cables, and performed other tasks necessary to complete attachment and installation of imaging equipment.

Camera mounting system

Cameras were inserted into a sleeve of 4.0-in. inside diameter steel pipe and secured to the sleeve with set screws. The pipe was welded to a flat plate with bolt holes drilled into the corners (Figure 6). The flat plate was bolted onto the nonmoving center support of the traveling screen. Each camera was aimed laterally looking across the surface of the traveling screen (Figure 4). Camera depth-of-view, based on the ability to identify structural features (bolt heads on the tie down bar), was about 18 to 36 in. However, smolts are so highly reflective when illuminated from the side that they could be detected at distances of about 36 in.

Camera locations

Screen contact, impingement, and behavior of the smolts as they were intercepted by an ESTS were imaged by three video cameras mounted on the nonmoving central support of the STS (Figure 4). The three cameras imaged the left screen panel. One camera was located near the top of the screen, a second camera was located near the middle of the screen, and the third camera at the bottom (toe) of the screen. An incandescent light source with a maximum intensity of 120 W was strapped to the pipe sleeve and aimed parallel to the aim of the camera.

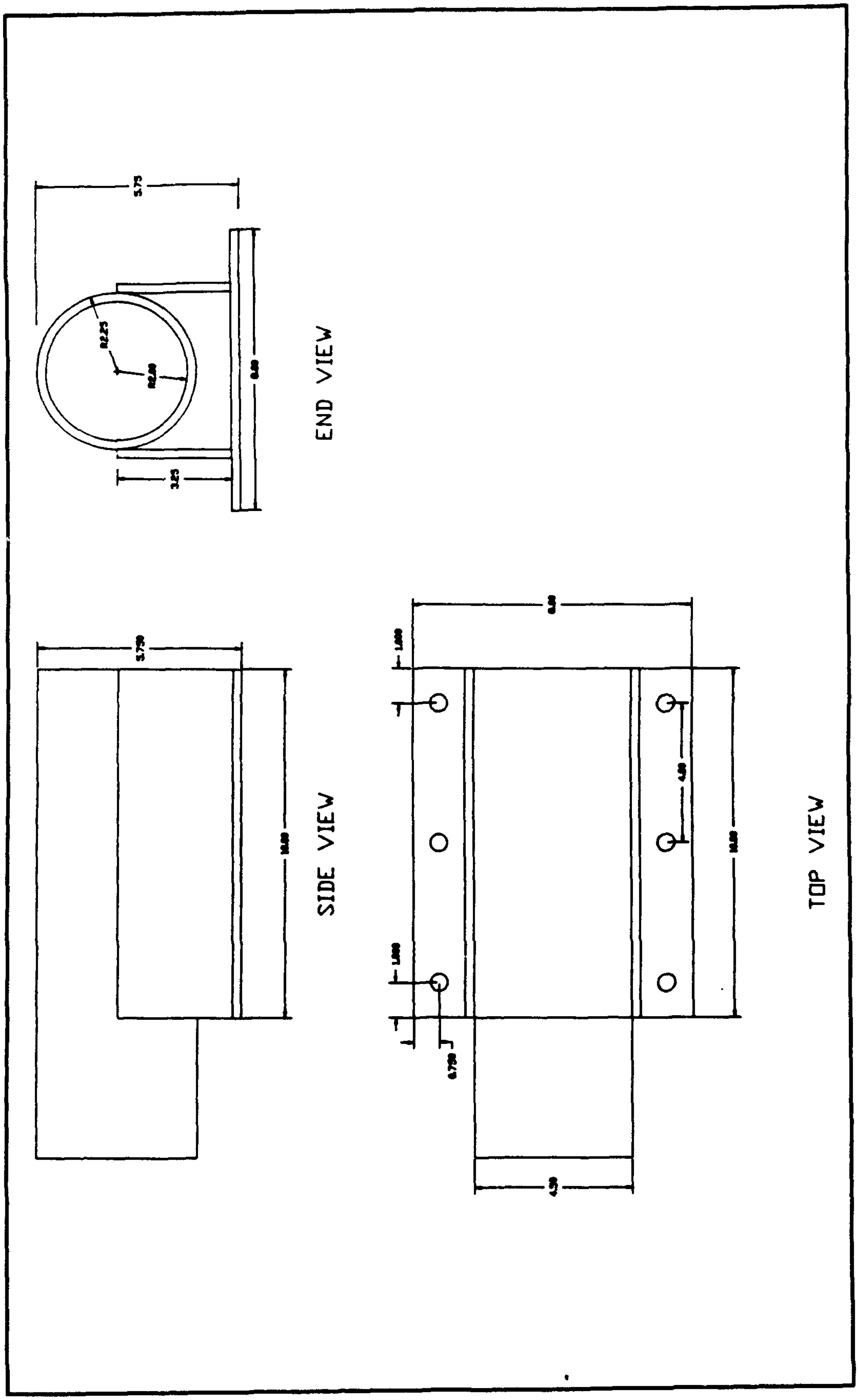

Figure 6. Camera mount design used to image smolts on submerged traveling screens

3 Data Analysis

Analysis of Video Imaging

Video camera images were recorded by a Sony VCR onto VHS video tape. Images of smolts being intercepted by the ESTS were consolidated onto a single video tape by selectively copying segments of the original video tapes that contained footage of fish onto a new tape using a second VCR. The consolidated tape was played back in slow motion, and values for variables describing screen contact, impingement, and interception behavior (hereafter collectively termed impingement behavior) (see Chapter 4—Table 1) were recorded by a technician. Particular emphasis was placed on relating impingement behavior (see Table 1 for description) to camera location and unit loading. A total of 338 interception events were recorded, and 336 interception events during 910 min of imaging were analyzed.

Data Recording

Using the consolidation tapes, a technician assigned an impingement code for each fish observed (Table 1). For purposes of analysis, a binary impingement index was created that had a value of "0" if the smolt did not contact the screen or a value of "1" if the fish contacted the screen. An impingement value of 1 was assigned even if the fish escaped from the screen because many of the escaping fishes were swimming laterally across the screen. It seems reasonable to expect these fishes to recontact the screen before they are transported up the gate slots because of the long length of time that would be required for the fish to "zig-zag" its way up the screen.

Data Summarization

An impingement proportion (R_IMPNG) for each camera location X unit loading category was obtained (see Chapter 4—Table 2) by summing values of the binary impingement index for each category (TOT_IMP) and dividing the sum by the total number of fish observed (TOT_SEEN). An imaging rate for each category was obtained by dividing the total number of fish seen (TOT_SEEN) by the duration (DURATION) of that category. Two additional summary impingement variables, TRNSDEAD (proportion of entrained fish showing no signs of life) and SCRNDEAD (proportion of fishes impinged on the screen showing no signs of life), were also determined.

Data Analysis

Analysis of variance (ANOVA) was used in the General Linear Models Procedure (PROC GLM) of the Statistical Analysis System (SAS Institute, Inc. 1988) to test for differences at $\alpha = 0.05$ in impingement proportions and imaging rates among camera locations and unit loadings. Differences among camera locations (three levels—top, middle, and bottom of the screen) were tested by pooling data by unit loading, whereas differences among unit loadings (three levels—12,000, 14,000, and 16,000 cfs) were tested by pooling data by camera location. A total of 13 observations were available for ANOVA because 12,000- and 16,000-cfs unit loadings were replicated (Table 2).

4 Results

Impingement behavior (Table 1), complete data summary (Table 2), data summaries by unit loading (Table 3), and camera location (Table 4) are presented below.

Table 1
List and Description of Impingement/Entrainment Variables

Variable	Description
Turbidity code S N J E	Type of turbidity measurement: For Secchi disk For NTU (Nephelometric Turbidity Unit) For JTU (Jackson Turbidity Unit) For estimated visibility
Screen Type Code MS BS	Type of screen design: Mesh screen Bar screen
Camera Type	First two letters of camera manufacturers and first two letters/characters of model number
Light System	First two letters of light system manufacturers and first two letters/characters model number
Crew Chief	First name initial and last name initial of field crew chief
SPP Code	Two-letter code for fish species
Life Stage	Two-letter code for life stage
Size	Obtain estimated size from fike net data
Tape Number	Archive code or number of video tape
Fish Number	In sequential order from top of code from beginning with "1"
Tape Location	Location in feet on video tape
CYCL STAT Code C N	Status of traveling screen: Cycling Not cycling

(Continued)

Table 1 (Concluded)	
Variable	**Description**
INPIN Type E P G I	Impingement type: Entrained but no impingement Entrained then impinged with no escape Entrained then impinged with escape for at least one panel Impinged fish, entrainment not observed
Approach Position Code 11 12 21 22	Position of fish as it approaches screen: Head first and dorsal side up Head first and dorsal side down Tail first back up Tail first back down
Approach Vertical Angle 00 90 180	Estimated vertical approach trajectory: Representing parallel to screen originating from upper screen Representing perpendicular to screen Representing origination from toe of screen
Approach Horizontal Angle + - 0	Estimated horizontal approach trajectory referenced to camera: Towards camera Away from camera Cannot determine
Retreat Variables Refer to Behavior After Impingement	These variables are to be filled in only if impingement is observed and not to be filled in if entrainment only is observed.
Life Signs + -	Condition of fish: Life signs evident No life signs evident
Number of Hits	Number of times a fish is observed to contact the screen
OPERC DAMA Y N	Operculum damage: Operculum bend back Operculum not bent back
IMPIN LOCAT HIT-1 MO TO MB TM	Location of fish for first observed screen contact: Fish hit mesh only Fish hit tie bar only Slid from mesh to tie bar Slid from tie bar to mesh
IMPING LOCAT HIT-2	Same as above except for second observed contact event for one fish; three or more hits are not considered.

Table 2
Summary of Collected Data

CAMLOC	UNITLOAD	DAY	TOT_IMP	TOT_TDEA	TOT_SDEA	TOT_SEEN	DURATION	R_PERMIN	R_IMPNG	R_TDEAD	R_SDEAD
BO	12	19	14	0	7	16	45	0.36	0.88	0.00	0.44
BO	12	20	2	0	2	2	90	0.02	1.00	0.00	1.00
BO	14	19	8	0	4	10	85	0.12	0.80	0.00	0.40
BO	16	19	26	0	20	47	60	0.78	0.55	0.00	0.43
MI	12	19	10	0	0	18	45	0.40	0.56	0.00	0.00
MI	12	20	14	0	0	30	90	0.33	0.47	0.00	0.00
MI	14	19	24	0	3	38	85	0.45	0.63	0.00	0.08
MI	16	19	34	0	3	55	60	0.92	0.62	0.00	0.05
MI	16	20	11	0	2	16	80	0.20	0.69	0.00	0.13
TO	12	19	4	0	1	28	45	0.62	0.14	0.00	0.04
TO	14	19	7	0	0	15	85	0.18	0.47	0.00	0.00
TO	16	19	4	2	3	43	60	0.72	0.09	0.05	0.07
TO	16	20	0	6	0	18	80	0.23	0.00	0.33	0.00

Note: Variable names are oriented vertically and defined as follows:

CAMLOC = camera location, BO = bottom of screen, MI = middle of screen, and TO = top of screen.

UNITLOAD = turbine discharge in cfs x 1000.

DAY = day of the month (July).

TOT_IMP = total number of smolts impinged on the screen per analysis stratum.

TOT_TDEA = total number of smolts that were entrained and showed no signs of life.

TOT_SDEA = total number of smolts that were impinged on the screen and showed no signs of life.

TOT_SEEN = total number of smolts observed per analysis stratum.

DURATION = duration of a sampling stratum in minutes.

R_PERMIN = rate (fish per minute) at which fish are observed on video tapes.

R_IMPNG = impingement rate (TOT_IMP/TOT_SEEN).

R_TDEAD = entrained fish (not touching screen) that exhibit no life signs divided by TOT_SEEN.

R_SDEAD = impinged fish that exhibit no life signs.

Table 3
Summary of Impingement Behavior Data Pooled by Unit Load (discharge)

UNITLOAD=12,000 CFS

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
5	RATE IMPINGED	0.61	0.34	56.02
	RATE TRNSDEAD	0.0	0.0	.
	RATE SCRNDEAD	0.29	0.44	147.80

UNITLOAD=14,000 CFS

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
3	RATE IMPINGED	0.64	0.17	26.34
	RATE TRNSDEAD	0.0	0.0	.
	RATE SCRNDEAD	0.16	0.21	132.70

UNITLOAD=16,000 CFS

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
5	RATE IMPINGED	0.39	0.32	81.76
	RATE TRNSDEAD	0.08	0.15	191.23
	RATE SCRNDEAD	0.13	0.17	124.78

Note: RATE IMPINGED = number impinged (touching screen)/total observed.
RATE TRNSDEAD = entrained fish exhibiting no life signs/total observed.
RATE SCRNDEAD = impinged fish exhibiting no life signs/total observed.
N Obs = number of different proportions tested.

Table 4
Summary of Impingement Behavior Data Pooled by Camera Location (Variables same as defined in Table 3. Note the higher impingement values associated with the bottom camera)

CAMERA LOCATION=BOTTOM OF SCREEN

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
4	RATE IMPINGED	0.81	0.19	23.33
	RATE TRNSDEAD	0.0	0.0	.
	RATE SCRNDEAD	0.57	0.29	51.24

CAMERA LOCATION=MIDDLE OF SCREEN

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
5	RATE IMPINGED	0.59	0.08	14.24
	RATE TRNSDEAD	0.0	0.0	.
	RATE SCRNDEAD	0.05	0.05	103.58

CAMERA LOCATION=TOP OF SCREEN

N Obs	Variable	Mean	Stand. Dev.	Coeff. of Var.
4	RATE IMPINGED	0.18	0.20	115.49
	RATE TRNSDEAD	0.09	0.16	168.93
	RATE SCRNDEAD	0.03	0.03	126.9A

Imaging Rate

Imaging rates varied between 0.02 to 0.92 fish per minute (Table 2). The variability within each treatment level was substantial. There was no statistical difference in imaging rate by unit loading or by discharge (Table 5). Based on NMFS data, approximately 2.63 fish/minute (325 fish/2 hr) are guided by standard screens. The imaging rate in this study was 0.37 fishes per camera (336 fish/910 imaging min). Video cameras were each imaging a swath about 2 ft wide (the depth of view—2 ft for each camera) on one side of the center support beam of a total screen width of 20 ft or about 10 percent of the screen width. Expanding the imaging estimate of 0.37 fish per minute to the total screen width would yield a passage rate based on video imaging of about 3.70 fish per minute. The difference between passage rates based on video imaging (3.70 fish/minute) and the passage rate based on FGE studies (2.6 fish/minute) was about 30 percent. This study's imaging rate of smolts was in approximate agreement with guidance rates estimated from gate well dipping. The imaging estimate is probably inflated, since it would be reasonable to expect that some of the same fishes were observed by more than one camera and that fishes imaged by the bottom camera and then carried under the lip of the screen would not be included by the NMFS as guided fishes.

Results from the pilot studies indicate that behavioral response to different parts of the screen is a critical component necessary to select, design, and operate diversion screens. Screen contact proportions were observed that varied between 0.99 percent for the bottom of the screen to 0.0 percent for the top of the screen (Table 4). Pilot study results indicate statistically significant differences at $\alpha = 0.001$ for screen contact proportions among screen locations (Table 6).

Qualitatively, smolts in the upper third of the screen were efficiently guided with minimal contact with the screen. Movement of smolts imaged by the middle camera appeared to be random. Some smolts imaged by the middle camera were observed moving towards the gate well, whereas others were seen moving away from the gate well towards the toe of the screen. Smolts in the bottom third of the screen seemed disoriented. The flow lines in this part of the screen transport the smolts towards the lip of the screen. However, it seems reasonable to speculate that the smolts would resist being entrained into the deeper water, since most fish seem to be surface oriented; that is, most passage occurs in the upper one-third of the water column. Consequently, the smolts are being carried towards the toe of the screen at a velocity (3 ft per second or greater) near their maximum swimming velocity.

Table 5
Results of ANOVA for Imaging Rate (the rate at which smolts were observed on video tape) by Camera Location and Unit Loading (Both Type I and Type III SS (sum of squares) are presented; however, Type III SS is more desirable because the hypothesis test for an effect does not involve parameters from other effects (SAS Institute, Inc. 1988))

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.47872368	0.05984046	0.55	0.7815
Error	4	0.43545139	0.10886285		
Corrected Total	12	0.91417507			

R-Square	C.V.	Root MSE	R_PERMIN Mean
0.523667	80.68333	0.32994370	0.40893665

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.04733483	0.02366742	0.22	0.8135
UNITLOAD	2	0.20106015	0.10053008	0.92	0.4680
CAMLOC*UNITLOAD	4	0.23032869	0.05758217	0.53	0.7238

Source	DF	Type III SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.01784079	0.00892040	0.08	0.9228
UNITLOAD	2	0.24283291	0.12141645	1.12	0.4122
CAMLOC*UNITLOAD	4	0.23032869	0.05758217	0.53	0.7238

Note: R_PERMIN = rate (per minute) at which smolts are imaged.
DF = degrees of freedom.
F value = model mean square error divided by the mean square error.
Pr > F = probability of randomly achieving this F value.
R-square = amount of the variability explained by the model.
C.V. = coefficient of variation.
Root MSE = square root of the Mean Square Error.

Table 6
Results of ANOVA for Proportion of Smolts Contacting the Screen (R_IMPNG) by Camera Location and Unit Loading (Variable names are the same as in Table 5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	1.06809320	0.13351165	28.90	0.0028
Error	4	0.01847979	0.00461995		
Corrected Total	12	1.08657300			

R-Square	C.V.	Root MSE	R_IMPNG Mean
0.982993	12.82434	0.06797020	0.53000935

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.82841584	0.41420792	89.66	0.0005
UNITLOAD	2	0.06750920	0.03375460	7.31	0.0462
CAMLOC*UNITLOAD	4	0.17216817	0.04304204	9.32	0.0264

Source	DF	Type III SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.56632832	0.28316416	61.29	0.0010
UNITLOAD	2	0.08541590	0.04270795	9.24	0.0316
CAMLOC*UNITLOAD	4	0.17216817	0.04304204	9.32	0.0264

Entrained—No Life Signs

Although the analysis was not statistically significant (too few fish—only eight total fish observed in this category), it is notable that this category of fishes was observed only at the top of the screen (Table 7). These fishes may have been injured prior to entry into the bypass system, or they may been injured at some other point on the screen and then transported towards the gate well. Injury to the smolts probably did not occur in this part of the screen.

Impinged—No Life Signs

The effect of camera location was statistically significant at $\alpha = 0.05$, and the effect of unit loading was not statistically significant (Table 8). Fish in this category ranged from 40 to 100 percent of the total fish observed at the bottom of the screen. No impingement rates over 13 percent were observed at either the top or middle of the screen.

Table 7
Results of ANOVA for Proportion of Fish Exhibiting No Signs of Life (R_TDEAD) (observed entrained but not contacting or touching the screens). (Variable names are the same as defined in Table 5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.06104247	0.00763031	0.74	0.6675
Error	4	0.04113335	0.01028334		
Corrected Total	12	0.10217581			

R-Square	C.V.	Root MSE	R_TDEAD Mean
0.597426	347.0596	0.10140679	0.02921884

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.02497192	0.01248596	1.21	0.3872
UNITLOAD	2	0.01246374	0.00623187	0.61	0.5890
CAMLOC*UNITLOAD	4	0.02360681	0.00590170	0.57	0.6981

Source	DF	Type III SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.00998877	0.00499438	0.49	0.6474
UNITLOAD	2	0.01127205	0.00563602	0.55	0.6161
CAMLOC*UNITLOAD	4	0.02360681	0.00590170	0.57	0.6981

Table 8
Results of ANOVA for Impingement of Fish Exhibiting No Signs of Life (R_SDEAD) (observed impinged on the screen). (Variables same as defined in Table 5)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.86937875	0.10867234	2.67	0.1796
Error	4	0.16306255	0.04076564		
Corrected Total	12	1.03244130			

R-Square	C.V.	Root MSE	R_SDEAD Mean
0.842061	99.91849	0.20190502	0.20206973

Source	DF	Type I SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.76554224	0.38277112	9.39	0.0308
UNITLOAD	2	0.01887219	0.00943609	0.23	0.8033
CAMLOC*UNITLOAD	4	0.08496431	0.02124108	0.52	0.7284

Source	DF	Type III SS	Mean Square	F Value	Pr > F
CAMLOC	2	0.55983665	0.27991833	6.87	0.0509
UNITLOAD	2	0.01793996	0.00896998	0.22	0.8116
CAMLOC*UNITLOAD	4	0.08496431	0.02124108	0.52	0.7284

Qualitatively, smolts in the area of the screen imaged by the bottom camera were subjected to multiple hits against the screen, particularly when the screen was cycling. During cycling, the fish that have become impinged on the bottom portion of the screen are moved upward along the screen. Once the fish reach the bottom lateral support member, local flow conditions first cause the fish to be washed off the screen surface and then to be pushed back into the approach flow where they are once again impinged back onto the lower portion of the screen. This cycle continues until the fish are impinged in such an orientation that they are carried past the lower lateral support member by the cycling screen. The violence of the multiple impingement events suggests that fish are either severely injured or killed on this part of the screen. Fish in this area that manage to escape impingement after their initial strike were pushed by the currents toward the lower lip of the screen where they probably were carried under the screen and into the turbine.

5 Discussion

Any effort to describe impingement on and smolt behavior to fish screens must address two potential experimental biases. First, the presence of the camera/light body and mounting hardware will produce a hydraulic anomaly on the screen that may potentially influence fish response if the anomaly is large enough to be detected by approaching fish. Second, the illumination field required for camera operation may also cause smolts to be attracted to or repelled from the immediate vicinity of the camera and, thus, also bias any results describing fish response to the screens.

Potential sampling biases resulting from the presence of the camera/light bodies and mounting hardware on the flat screen surfaces can be minimized in several ways. The cameras used at McNary Dam could provide adequate images under relatively low light conditions. The illumination field for the pilot tests at McNary Dam was provided by approximately 120 W of power to the light source. The intensity of the light source was not measured.

The bias resulting from the presence of the illumination field may not be as severe a problem as it appears. The authors' experience with lights suggests that the effects of an illumination zone are highly localized. Fish outside an illuminated area are unaware that it exists because of the rapid attenuation of light in turbid water. Fish must accidentally enter a lighted area to be influenced. Light should not attract fish into the illuminated zone that would not have entered into an illuminated zone anyway.

The light system can influence the behavior of the fish or impingement rate once the fish have entered into the illumination zone. However, identical lighting was used for all cameras so that the effect of the lighting system on smolt behavior or impingement rate estimation would be a constant bias in the analysis as opposed to a random or fluctuating bias. While it is not possible to presently quantify the extent of the bias, it is possible to anticipate the direction of the bias and thus provide a "worst case" estimation of the effects of the bias introduced by lights. Without light, the smolts can use only the octavo-lateralis system to sense the presence and location of the screen. With light available, the smolts can also use vision to locate the screen. Consequently, if there is a light bias, it is

speculated that this bias should function to reduce impingement rate if all other factors are equal.

Information on fish behavior can also provide some insight into the direction of bias introduced by the presence of the light system. The response of fishes to light is partially determined by antecedent illumination conditions, because fish acclimate to ambient light conditions. If fish are removed from ambient light conditions, they will attempt to return to those conditions. Thus, fish held under daylight conditions and then quickly introduced into a test chamber under low light conditions will not respond the same as fish held in low light and then introduced into a low light condition. Moreover, fish held under daylight conditions tend to be attracted by daytime light conditions. Similarly, fish held under low light conditions will not respond to daytime light conditions the same as fish held under daytime light conditions and introduced into high light conditions. If active, fish held in low light conditions will tend to seek low light conditions.[1] In nighttime tests of different lighting systems at Richard B. Russell Dam, it has been observed that a time duration of approximately 45 min must pass before blueback herring respond (in this case they are attracted) to underwater lights. It seems doubtful that the few seconds of illumination available to smolts as they are intercepted by the screens is adequate to modify their behavior substantially from their behavior under low light conditions. If there is a behavioral modification, the smolts would probably try to avoid the most intense part of the illumination field. Based on the above rationales, the authors feel that the results of this study have substantial value.

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1 Personal Communication, March 1991, James Anderson, Associate Professor School of Fisheries, University of Washington, Seattle, WA.

6 Conclusions

Conclusions based on this pilot study are summarized below.

- It is possible to use existing technology to successfully image smolts as they approach and are intercepted by traveling bypass screens. If camera attachment problems can be overcome, it seems reasonable to be able to image smolts on bar screens also.

- Impingement of smolts on the screens is highly dependent on the local hydraulic conditions on the screen. The results from the pilot studies demonstrated that impingement of smolts on the screen must be described and evaluated in terms of the spatially variable hydraulic environment of the screen, because camera location was a statistically significant variable describing the impingement of smolts.

- The bottom third of the ESTS probably has a severe negative effect on smolt survival, because flows move toward the toe of the screen and not toward the gate well. Qualitative data indicate that smolts tend to be surface oriented as they migrate. While it cannot be proven, it seems reasonable that smolts would swim against flow patterns that would tend to drive them deeper into the water column. The water velocity in this part of the screen is near or above smolt swimming speeds. Smolts may be swimming to exhaustion and then impinging on the screens.

- Past studies conducted to determine the FGE and survival rate of smolts passed through the turbines would have missed the effect of the bottom one-third of the screen on smolts, because the affected smolts would have been passed under the lip of the screen and through the turbine. In fact, injury or death to smolts caused by the lower one-third of the screen would have been evaluated as turbine damage and not as screen-induced damage.

- While impingement of smolts on the middle camera was not as severe as that observed on the lower camera, it was noted that a number of fish were not being guided towards the gate well, but, instead, were actively swimming towards the bottom of the screen.

The fate of these fishes is unknown, although it seems a reasonable speculation that they will either be subjected to the high rates of impingement observed at the bottom of the screen or that they will be impinged on the screen after swimming to exhaustion. Potentially, a proportion of the smolts entering the lower one-half of the ESTS (or any screen design that has similar hydraulic pattern) may be injured by impinging on the screen.

- Significant differences between both impingement rate (number fish touching screen/number fish observed) and dead-on-screen rate (number of fish on screen exhibiting no apparent signs of life/number of fish observed) were obtained between different zones of the screen. It would appear that impingement rate over the face of one screen may vary much more than an overall impingement rate between screens based on imaging performed at one comparable position on two or more screens. Consequently, comparison of screen design or deployment alternatives must be made by separating the screens into relatively homogenous areas, then describing how impingement and approach behavior vary by area, and integrating effects across areas to obtain an overall effect for a particular screen design or deployment alternative.

- A much more detailed imaging study should be performed as a follow-up to this pilot study.

References

Fletcher, I. (1985). "Risk analysis for fish diversion experiments: Pumped intake systems." *Transactions of the American Fisheries Society* 114, 652-694.

SAS Institute, Inc. (1988). *SAS/STAT User's Guide*. Release 6.03 Edition, SAS Institute, Inc., Cary, NC.

Appendix A
Specifications for a Photosea "Nighthawk" ICCD Camera

Outland Technology UWC-160 Underwater video camera:

Low light sensitivity—1 FC Minimum Illumination.

8.5 mm, f1.3 Auto Iris.

Low power 12 VDC at 270 ma.

Medium size 9.25 cm diam—25 cm long.

Weight in air, 2.1 kg—in water, .36 kg.

Cost to buy—camera, $7,650; power supply, $1,200.00; cable $4.90/ft.

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13. ABSTRACT *(Maximum 200 words)*

Extensive bypass facilities have been installed at Corps of Engineers dams on the Columbia River system to intercept and bypass out-migrating salmon smolts before they enter the turbines. However, the performance of different screen designs and deployment configurations is incompletely known because the deep water, high turbidity, and rigorous hydraulic environment in the intakes prevent direct observation. Underwater video imaging was used to characterize the behavior of smolts as they approach and are influenced by the bypass screens. The objectives of this pilot study were to design and deploy an underwater video camera system to (a) assess smolt screen contact and impingement rates on extended-length slanted traveling screens (ESTSs) at different screen locations and different turbine loadings and (b) and describe the response of smolts as they approach and are intercepted by ESTSs. Significant differences between contact rates on different parts of the screens were observed. The conclusion was that screen contact and impingement rates are highly dependent on local hydraulic conditions on the screens. In addition, the bottom third of the ESTS exhibits significantly higher impingement than the upper third or middle of the screen. Thus, comparison of screen design or deployment alternatives must be made by looking at impingement and approach behavior for similar areas of the screens and integrating effects across areas to obtain an overall effect for a particular screen design or deployment alternative.

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